

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 2/32

The proposed changes for FIGS. 1A and 1B are to show an array of side-polished fiber-optic apparatuses; this is supported by the text and claims of the original application, and no new matter is added.

The proposed changes for FIG. 3 is to add additional grooves perpendicular to those already shown; this is supported by the text and claims of the original application, and no new matter is added.

Corresponding changes (and references to new callout numbers) are requested below in the amendments to the paragraphs of the specification, and these changes are discussed under Remarks below.

#### Amendments To Specification

For improved wording and to add the inventor's name and the recently issued patent number to the reference in the first paragraph, replace paragraph [0001] on page 1 with the following amended paragraph:

*B1*  
[0001] A co-pending application entitled "Structures and Methods for Aligning Fibers", having application number 09/825,821, filed on 4 April 2001 by Tullis, now U.S. Pat. No. 6,188,058, is entirely incorporated herein by reference.

To add the recently issued patent number to its reference, replace paragraph [0008] on page 4 with the following amended paragraph:

*B2*  
[0008] None of the above art, with the exception of a co-pending application entitled "Structures and Methods for Aligning Fibers", by Tullis, now issued as US Pat. No. 6,516,131, teaches methods or apparatuses for facilitating the placement of an array of fibers into an array of grooves of width comparable to the diameter of the fiber.

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 3/32

To replace a blank with a hyphen between "fiber" and "optic" in three places, replace paragraph [0012] on pages 5-6 with the following amended paragraph:

*B3*

[0012] The objects of the invention are primarily twofold. One object is to provide new methods for low-cost manufacture of side-polished fiber optics, for use both singly and in compact arrays. These new methods involve process steps, many of which operate on many apparatus units simultaneously, with little additional manual labor over what is required to produce one unit at a time. The other primary object is to create high level assemblies of these fiber-optic apparatuses in compact arrays that not only save space but also allow for easy interconnection. Examples of apparatuses that can be made with the disclosed integrated side-polished fiber-optic technology include optical pass-throughs, attenuators, polarizers, couplers, multiplexers, taps, splitters, joiners, filters, modulators and switches. By interconnecting elements within compact integrated arrays of these apparatuses, complicated photonic circuits can be readily constructed, examples of which include a many-to-one multiplexer, a one-to-many demultiplexer and cross-point switch arrays. The reader will readily appreciate the novel methods and structures used to realize manufacturable fiber-optic apparatuses and circuits for performing needed all-fiber photonic functions.

To clarify that coiling a fiber doesn't mean breaking it, replace paragraph [0014] on page 7 with the following amended paragraph:

*B4*

[0014] By using fiber-core gratings and/or surface gratings in regions of the side-polished areas and coiling a fiber unbroken around to loop through one adjacent V-groove per cycle along a strip, compact multi-channel optical add-drop multiplexers (OADMs) are easily constructed.

To clarify the brief description of FIG. 1 in keeping with the proposed amendment to FIG. 1, replace paragraph [0016] on page 7 with the following amended paragraph:

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 4/32

[0016] FIG. 1 shows how varying the widths of face-to-face grooves, and alignment with a sliding, even slightly rotatable, fiber key, can facilitate the tuning of coupling efficiencies in an array of 4-port fiber-optic apparatuses made with side-polished fibers. The array is shown also having multiple 2-port fiber-optic apparatuses.

To clarify that wrapping a fiber in loops doesn't mean breaking it, replace paragraph [0023] on page 8 with the following amended paragraph:

[0023] FIG. 8 shows a method and means by which to form a multi-channel optical add-drop multiplexer from both a first strip of half-couplers and a second strip of half-couplers, wherein the second strip has a common, unbroken fiber wrapped in recirculating loops through the strip. Either one or both fibers at each coupling region between two side-polished areas would have a core-based or surface-based, wavelength-selective grating.

In order to a) correct an incomplete figure reference by changing "FIG" to "FIG. 1B" in the first line, b) to insert the recent issue number of the referenced co-pending patent application, c) to insert an alias of "alignment fiber" for "sliding fiber key", and d) to clarify the description of FIG. 1 in keeping with the proposed amendment to FIG. 1, replace paragraph [0025] on page 9 with the following amended paragraph:

[0025] Reference is now made to FIG. 1, which consists of two parts, FIG. 1A and FIG 1B. FIG. 1 shows multiple 4-port and 2-port fiber-optic apparatuses arranged in an array, wherein multiple 4-port fiber-optic apparatuses can be tuned by translation and/or rotation constrained by an alignment-keying fiber. Thus the art presented and claimed in the copending U.S. patent application titled "Structures and Methods for Aligning Fibers", by Tullis, now issued as US Pat. No. 6,516,131, for aligning a single 4-port apparatus is expanded for aligning arrays of 4-port apparatuses. FIG. 1 shows how varying the widths of face-to-face grooves to create tapered channels, as well as alignment by sliding with a fiber key (called an alignment fiber) in one of these channels, can facilitate the tuning of coupling efficiency within multiple 4-port apparatuses. Each 4-port apparatus can be any of the group including couplers, add-drop multiplexers, taps, splitters, joiners, filters,

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 5/32

*[Handwritten notes: B7, Add, P1]*  
modulators and switches. The tuning is accomplished by adjusting the interaction length between two evanescently coupled fibers. And additional alignment grooves and their alignment fibers may also be included.

In order to a) improve clarity on the use of the term "alignment fiber", b) to insert an observation of a point that should be obvious to one skilled in the field and given what is disclosed, c) to replace a blank with a hyphen between "fiber" and "optic" in two places, and d) to clarify the description of FIG. 1 in keeping with the proposed amendment to FIG. 1, replace paragraph [0026] on pages 9-11 with the following amended paragraph:

*[Handwritten notes: B7, Add, P1]*  
[0026] FIG. 1A shows a tunable array of 4-port fiber-optic apparatus 1 interspersed with 2-port fiber-optic apparatuses. The 4-port fiber-optic apparatuses may not be all alike; for example one may be a coupler, while another might be an add-drop multiplexer. The 2-port fiber-optic apparatuses 5A and 5C may not be all alike; for example one may be a polarizer, while another might be an attenuator. The array of 4-port apparatuses 1 is comprised of two arrays of half-couplers 2 and 3. Each of these two arrays of half-couplers 2 and 3 is comprised of side-polished fibers installed within respective varying-width V-grooves, for example etched into 100 crystal surfaces. A first array of half-couplers 2 is shown comprised of a substrate 10 having a surface 8 containing varying-width grooves 6, 6A, and 6B. A second array of half-couplers 3 is shown comprising a substrate 11 having a surface 9 containing varying-width grooves 7, 7A, 7B, and 7C. The two substrates 10 and 11 are placed with their respective surfaces 8 and 9 face-to-face with the grooves of one aligned at least approximately with grooves of the other. The two substrates can be slid over one another in the direction parallel to the long axes (axes not shown) of the side-polished areas 12, 13, 12B, and 13B. The two side-polished areas 12 and 13 are shown at a position where they overlap one another, as are the two side-polished areas 12B and 13B. The side-polished areas 12, 12B, 13, 13A, 13B, and 13C each have an elliptical shape with long axes parallel to the groove axes (not shown). The arrows 14 and 15 indicate the direction of motion desired. The side-polished areas of the fibers 5A and 5C don't have matching areas of another fiber to overlap, however notice that the side-polished area of fiber 5A has a region of space above it created by the groove

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 6/32

6A that lies above it, whereas the side-polished area of fiber 5C doesn't have a groove above it and thus faces the surface 8 of substrate 10. The space above the fiber 5A and its side-polished area 13A, that is the space within the groove 13A would be filled with a gas, a liquid, a fluid containing one or more bubbles, or a solid filler material. The apparatus 1 is additionally comprised of a third fiber 16 which serves as an alignment fiber. Fiber 16 is in a bi-directionally tapered channel 17 constructed of two additional varying-width V-grooves 18 and 19 etched into the surfaces 8 and 9, parallel to grooves 6, 7, 6B, and 7B but offset from them. Fiber 16 serves as an alignment key within this channel 17, but allows for the motion described with which to tune the coupling ratio and efficiency of the 4-port assembly. By eliminating any linear portion to the channel 17, the two half-couplers 2 and 3 may be allowed some rotation which is easy to control with the substrates being of a significant scale larger than the side-polished areas, but remain well aligned in the direction of offset just described. One skilled in the art will immediately appreciate that a sliding action along an alignment fiber, or along possibly multiple and parallel alignment fibers, can tune an array of 4-port side-polished fiber-optic apparatuses. And one skilled in the art will also immediately appreciate that a relative rotation of the two substrates, constrained by one or more alignment fibers in their respective and parallel bi-directionally tapered channels, will affect the tune of a 4-port fiber-optic apparatus more, the more distant it is from a center of rotation. This is useful, for example, to optically compensate for a gradient in sidewall thickness often existing across an array of optical fibers. Yet another advantage of the bi-directionally tapered channels 17 and those formed by grooves 6 and 7, 6A and 7A, 6B and 7B, and by 7C alone is that the fibers 16 alone, 4 and 5, 5A alone, 4B and 5B, and 5C alone will experience less chance to be bent and strained entering or leaving their respective channels than were the channels of constant cross-section. The taper at the ends of these channels can be accentuated to help achieve additional avoidance of strain on the fibers 16, 4 and 5 from otherwise being bent about a sharp edge. It is important in high-bandwidth fiber-optic applications, such as in modern data- and telecommunications networks, to avoid straining fibers. This is because strain induces birefringence in the fiber and this causes polarization mode-dispersion that can result in high bit-error-rates.

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 7/32

To improve readability and to clarify the description of FIG. 1 in keeping with the proposed amendment to FIG. 1, replace paragraph [0027] on page 11 with the following amended paragraph:

*JG  
Jab.  
CH*

[0027] FIG. 1B shows an end-view of the apparatus illustrated in FIG. 1A with all similar parts identified by the same numbers, except the view is as though the fibers 4, 4B, 5, 5A, 5B, 5C, and 16 were terminated at the midpoints of the channels. In addition, the cores, such as 20 and 21 to fibers 4 and 5 respectively, are depicted as shaded disks or spots. Note how in this view, the interface between the two side-polished areas 12 and 13 (and between the two side-polished areas 12B and 13B) is a region of mutual contact. And note for example, how the side-polish on the fibers 4 and 5 has allowed the cores 20 and 21 to lie closer to one another to cause better evanescent coupling of light waves between the two cores 20 and 21.

To add the inventor's name and the recently issued patent number to its reference, replace paragraph [0031] on page 12 with the following amended paragraph:

*B10*

[0031] FIG. 2B then shows that the fiber 30 is placed within the groove 32 in the substrate 31, wherein the depth of the groove at its shallowest point positions the fiber 30 such that a portion of the side-wall 34 remains above the surface 33. To accomplish this placement of the fiber 30 within the groove 32, intermediate steps (not shown) may use methods and apparatuses as are disclosed in the copending patent application titled "Structures and Methods for Aligning Fibers", by Tullis, now issued as US Pat. No. 6,516,131. In the current invention, however, dissolvable or meltable bonding materials (used as tacking materials) or other suitable bonding materials 35 and 36 are placed under and over the fiber 30 as depicted with shading in regions 37, 38, and 39. These tacking materials 35 and 36 are used to hold the fiber 30 in place for the subsequent polishing step whose results are illustrated in FIG. 2C. The materials 35 and 36 may be different from one another, or they may be the same.

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 8/32

In order to correct the spelling of "removable" and to improve clarity by inserting a word definition of what is meant by "free-standing", replace paragraph [0033] on page 13 with the following amended paragraph:

*B11*

[0033] Thus the steps of figures FIG. 2A through 2C accomplish the making of what we will call here a first half-coupler 40, or substrate-supported half-coupler, as shown in FIG. 2C. One aspect of the current invention, over the previously disclosed art found within the above cited U.S. patents by Tseng, is that the bonding material 35 and 36 used here need not be wicked into place from the ends of the groove 32. Also, for subsequent method steps to be described below, the material 35 and 36 can be chosen to be dissolvable, meltable, or otherwise removable, with a minimum of disturbance to the side-polished fiber 42 within the associated groove 32. If at this point (shown in FIG. 2C) the bonding material was to be removed (not shown), it would allow removal (not shown) of the side-polished fiber 42 from the substrate 31 to create what we will call here a free-standing half-coupler (not shown). A free-standing half-coupler is one that is free of any attached substrate 31 being very near to the region of side-polish or simultaneously to both sides of this region. Generally throughout this disclosure, "free-standing" will mean that any rigid supporting element is not in direct contact with more than one of the group consisting of a) a first side, b) a second side, or c) a region. Within this definition, the terms "first side", "second side", and "region" refer to respective segments of fiber length along the longitudinal axe(s) of side-polished optical fibers in and about a region of side-polish.

To add clarity to the description of FIG. 3 in keeping with the proposed amendment for FIG. 3 to add perpendicular grooves (as disclosed in paragraph [0041]), replace paragraph [0045] on pages 17 and 18 with the following amended paragraph:

*BTX  
Nob.  
M15*

[0045] In FIG. 3, a substrate 70 is shown in a plan view 71, a side-view 72, and an end-view 73. A first group of grooves is shown including two arcuate grooves 74 and 75 and three constant-width grooves 76, 77, and 78, in an alternating sequence within surface 81, wherein all the grooves 75 through 78 are parallel to one another. A second group of additional grooves 84, 85, and 86 is shown perpendicular to the first group. Preferably, the

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 9/32

*b6  
b7c*

*B12*

widths and depths of the straight grooves 76, 77, and 78 are equal to or larger than the widths of the arcuate grooves 74 and 75 where the arcuate grooves 74 and 75 reach the ends 79 and 80 of the substrate 70. The surface area left un-etched 81 between these grooves should be minimized in order to facilitate the parting of substrates (31 and 58 in FIG. 2I) placed with these faces (31 and 52 in FIG. 2I; 81 on the substrate illustrated in FIG. 3) touching one another. The substrate 70 illustrated would be able to accept two optical side-polished fibers, one in each arcuate groove. A linear array of more numerous arcuate grooves can be etched into a common substrate, with one or more extra parallel grooves (illustrated as constant-width and constant-depth grooves in FIG. 3) interleaved between them, but only two arcuate grooves and three extra parallel grooves are illustrated in FIG. 3 for drawing simplicity. As was discussed above, the purpose of the extra parallel grooves is at least two-fold. One such purpose is to act as a barrier against spreading of permanent bonding material when fabricating a freestanding coupler. Another such purpose is to provide air access channels when parting two such surfaces that have been put face-to-face against one another. Also as discussed above, the purpose of the second group of additional and perpendicular grooves 84, 95, and 86 is to provide channels for access of air (or other fluid), for UV light to cure UV adhesive, and for parting tools, but they too can be used to limit flow of adhesive and reduce the area of bonding between two face-to-face substrates.

To add the inventor's name and the recently issued patent number to its reference, replace paragraph [0054] on page 21 with the following amended paragraph:

*B13*

[0054] FIG. 5 shows a means 110, adapted from the copending patent application entitled "Structures and Methods for Aligning Fibers", by Tullis, now issued as US Pat. No. 6,516,131, by which to align and place an array of fibers 111 into an array of substrate grooves 112 within a substrate strip 113. Referring back to FIG. 4, this shows a means by which the arrays of fibers 95 or 100 may be efficiently batch processed to place them into their respective arrays of substrate grooves found within their respective substrate strips 94 and 99. In FIG. 5, two of the fibers of the fiber array 111 are labeled as pair 114. A corresponding pair of substrate grooves 115 of the array of grooves 112 is also shown.

App. No. 09/837,325; Filed: 04/18/2001; Barclay J. Tullis et al.; GAU 2839 ; Amnt. B

p 10/32

To clarify that wrapping a fiber in loops doesn't mean breaking it, replace paragraph [0058] on page 22 with the following amended paragraph:

*B14*  
[0058] Although not shown in FIG. 5, it can easily be envisioned that two or more of the fibers (e.g. 114) may be actually uncut segments of a single, unbroken fiber which is continuous and looped around the substrate 113 to occupy multiple block grooves (e.g. 118) and multiple grooves (e.g. 115) of the substrate 113.

To clarify that looping a fiber doesn't mean breaking it, replace paragraph [0061] on pages 23 and 24 with the following amended paragraph:

*B15*  
[0061] FIG. 8 shows the manufacture 170 of a multi-channel optical add-drop multiplexer 171 (OADM). Many other apparatuses, such as a one-to-many power splitter, can be created using a similar structure. This add-drop multiplexer 171 is made from a first strip of half-couplers 172 and a second strip of half-couplers 173. The fiber 174 used in this second strip is a single, unbroken fiber and runs in loops to pass once through each of the individual grooves of the substrate strip 175. Preferably, the loops formed by the fiber 174, together with the plane of the substrate 175, all lie close to a common plane for compactness. One skilled in the art will appreciate that many optical losses from interconnections, including splices, can be avoided by this looping of a single, unbroken fiber in simultaneously forming multiple photonic apparatuses such as 4-port add-drop multiplexers. The detailed steps of fabrication can be taken from those described and illustrated with reference to FIG. 2 above. What is formed can be a many-to-one combiner or multiplexer or a one-to-many splitter or demultiplexer. If a demultiplexer is intended, one skilled in the art will know to include a grating within the fiber at the region of the side-polish and/or between the two side-polished areas of the two fibers comprising the 4-port apparatus. With the addition of a film or slice of an electro-optically or thermally active material (for example a suitable polymer or crystal), sandwiched within the interface between the two side-polished areas of the fibers, switching arrays can be formed in a similar manner to the above. By stacking multiple units of the OADM strip structure